On Use of "Crystal Funnels" and New Paradigm of High Energy Particle Colliders

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1. Current paradigm of particle accelerators is not sustainable as it requires more and more beam power, inevitable with energy increase. Indeed luminosity is

$$L = f_{rep}\frac{N_B N_p^2}{4\pi\sigma^2} = \gamma f_{rep}\frac{N_B N_p^2}{4\pi\beta^*\varepsilon} \qquad (1)$$

while beam power is $P=N_B N_p f_{rep}\gamma$, therefore luminosity grows as $L\sim P$ or P^2 (depending on whether all the power can be put in a single bunch or not, or whether there is flexibility to trade energy for beam power or not .. usually, not). Also, high energy physics demands usually grow with energy as $L_r\sim\gamma^2$ because of characteristic cross section decrease with energy. That imposes additional pressure on beam power as more and more of it needed for higher and higher energies. Usually, higher beam power means higher total power for HEP facility. Indeed, most recent colliders have

Tevatron	2 TeV	40-55 MW
LHC	7 TeV	100-150 MW
ILC	0.5 TeV	230 MW
CLIC	3 TeV	560 MW
Muon Coll	4 TeV	150 MW

Certainly, there is a limit how much power HEP facility can count on (eg dependent on operational cost of power ….0.05 $/kWh now in the US).

2. From Eq (1), one can see that going to smaller and smaller beam sizes at the IPs should help to ease the power requirements, and indeed, historically the luminosity of the colliders grew much faster than the energy (because of exactly that reason – smaller sizes by means of either smaller emittances or beta-functions or both) – see Fig.1a and b.

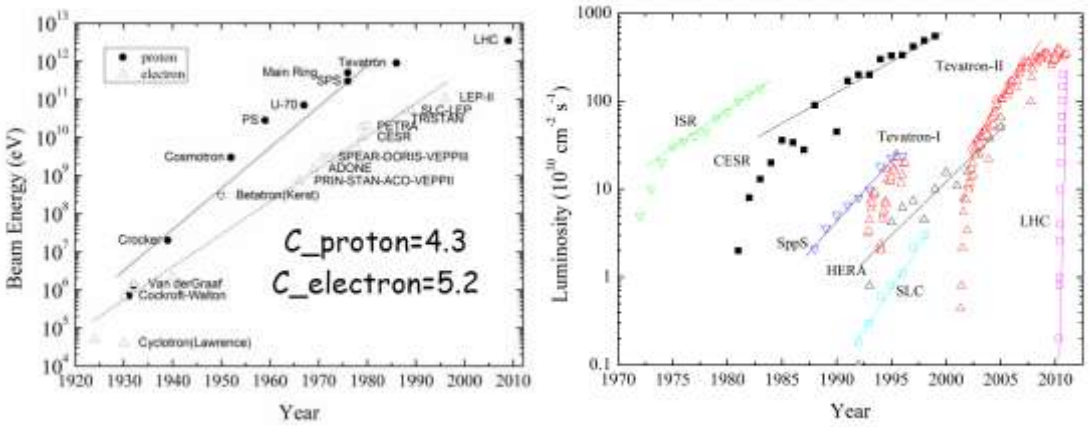

Fig.1: (a)Energy of accelerators grew as $E \sim exp(T/C_E)$, C_E=4.3-5.2 years; (b) (a) Luminosity of accelerators grew as $L \sim exp(T/C_L)$, C_L=2-4 years (average about 3.2 yrs)- from Ref.[1].

3. We propose to explore that path – of smaller beam sizes - to the extreme – and consider VERY high energy and high luminosity collider in which three ideas are exploited:

   I. Use of positively charged muons as the only particles which at high energies do not radiate much of energy while under impact of forces (that's what electrons do), and do not interact with materials - no nuclear interactions - if they pass thru the matter (that's what protons do)

   II. Acceleration of muons to high energies can be possible in crystal structures as proposed in Ref.[2]. It becomes more attractive now as high power fluxes of X-rays are now available from SASE X-FELs (eg LCLS, Spring-8 and XFEL Hamburg) – see Fig.2. One can hope that at least 1-10 GeV/m will be possible, and that crystal structures can be fibers , so the multi-km accelerators can be wound almost as well as optical fibers can be

wound up, allowing 10-1000 TeV energies. Channeling of muons without loss in such structures is essential.

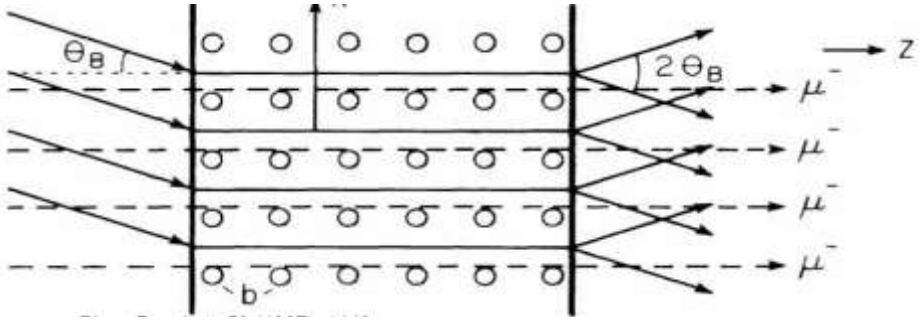

Fig.2 From Ref.[2] – acceleration of muons by crystal waves excited by Xrays

III. Most importantly, the new paradigm assumes very small beam intensities compensated by very small beam sizes of colliding beams – as small as atom-to-atom distances in crystals [3]. That can be achieved by channeling muons through consequently narrowing crystal dislocations – e.g. like in Fig.3. At the end all (or most) of the muons will end up in 1 Angstrom cell – and that's where Interaction point of muon collider will be set (so, another muon accelerator will need to deliver similarly small muon beam to exactly the same spot).

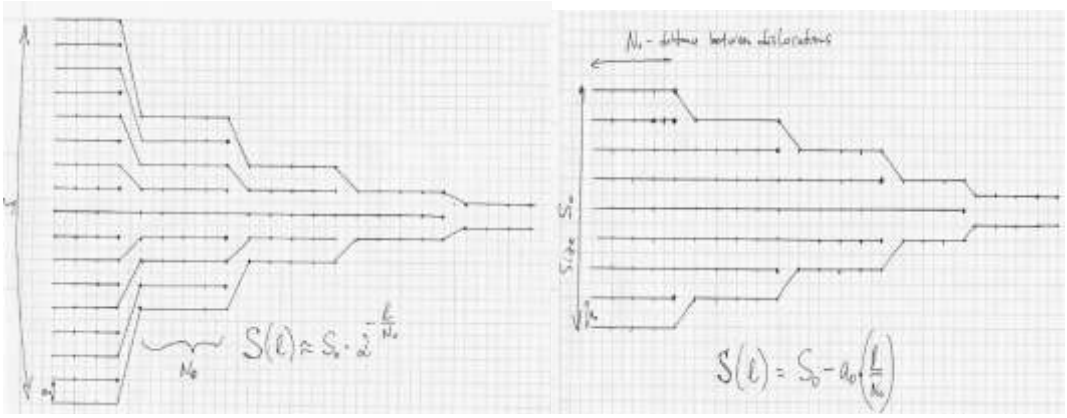

Fig.3 : Possible "crystal funnel" arrangements

4. Luminosity of such a collider – see Eq.1 - can be estimated as $L \sim 10^{30}$ $cm^{-2}s^{-1}$ if f_r=10kHz, N_p=100,000 muons per bunch and σ=1Angstrom/sqrt(12).

Correspondingly, the beam power will be P=200kW in each beam. Schematically, the paradigm shift can be illustrated as in Fig.4 from [3] :

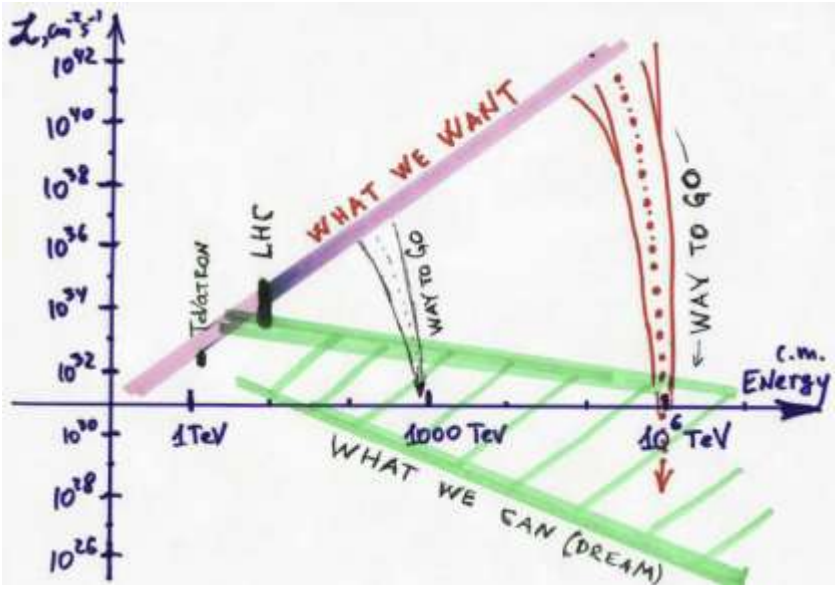

Fig.4 : Required change of HEP accelerators paradigm

5. To proceed along that (very attractive way), one needs to concentrate R&D efforts on three things : a) generation of 10^5-10^6 muons in small phase space; b) achievement of 1GeV/m to 10GeV/m accelerating gradients first in straight crystal structures, then in bent crystal fibers… with high energy transfer efficiency, say ~2-10%; c) feasibility of crystal funnel concept and its efficiency for muon beam focusing.

References:

[1] V.Shiltsev, Mod. Phys. Lett. A, v.26, issue 11 (2011) pp. 761-772

[2] T.Tajima,Cavenago, Phys. Rev. Lett. 59 (1987), 1440

[3] V.Shiltsev, U,Chicago talk "Do Acceleratpors Have Future" (2009), see in beams-doc-3532